AIR COMMAND HEADQUARTERS

OPERATIONAL RESEARCH DIVISION

PROJECT REPORT 95/1

THE ECONOMIC AND OPERATIONAL IMPACT OF JP-4 TO JP-8 CONVERSION

BY

G.V. Thio and P.E. Desmier

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OPERATIONAL RESEARCH DIVISION

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G.V. Thio* and P.E. Desmier

Operational Research Division Project Reports present the considered results of project analyses to sponsors and interested agencies. They do not necessarily represent the official views of Air Command Headquarters.

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ABSTRACT

This study compares the quantitative and qualitative factors associated with the conversion to JP-8 aviation turbine fuel for Canadian Forces (CF) land-based aircraft. The potential economic impact of conversion is studied for 4 Wing Cold Lake, 8 Wing Trenton, 14 Wing Greenwood and 19 Wing Comox. The operational impact of conversion is studied for the CF-18A (Hornet), the CP-140 (Aurora) and the KC-130 (Hercules) aircraft.

It is concluded that a conversion from JP-4 to JP-8 would result in an annual net loss to the CF of approximately $2.6M. It was further determined that the net loss is highly sensitive to the JP-8 purchase price due to the large volumes of fuel that must be purchased. However, taking into account the net loss and the positive affects in regards to safety, health, environmental considerations and operational benefits, it is recommended that conversion to JP-8 take place provided that operational limitations with regards to cold weather start-up for the CH146 (Griffon) be addressed.

RÉSUMÉ

L'étude fait une comparaison des facteurs qualitatifs et quantitatifs reliés à la conversion du carburant JP4 au JP8 pour les aéronefs des Forces canadiennes. L'impact économique possible est évalué pour les escadres suivantes : 4 Ere Cold Lake, 8 Ere Trenton, 14 Ere Greenwood et 19 Ere Comox. L'impact opérationnel est étudié pour les aéronefs Hornet CF-18A , Aurora CP-140 et Hercules KC-130.

L'étude conclue qu'une telle conversion entraînerait une perte annuelle nette d'environ $2,6 millions pour les Forces canadiennes. Cette perte est directement reliée au prix d'achat du carburant JP8 et à la grande quantité qui doit être achetée. Cependant, si on considère cette perte à la lumière des effets positifs sur la sécurité de manutention, la santé des travailleurs, les considérations environnementales et les avantages opérationnels, il est recommandé que la conversion au carburant JP8 se fasse du moment qu'on règle les problèmes de démarrage par temps froid du CH146(Griffon), problèmes qui réduiraient la flexibilité opérationnelle.

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

ABSTRACT/ RÉSUMÉ i

ACKNOWLEDGEMENT ii

EXECUTIVE SUMMARY iv

1 - INTRODUCTION 1

2 - FUEL DESCRIPTIONS AND PROPERTIES 2

3 – FUEL COSTS 2

4 Wing Cold Lake 3

8 Wing Trenton 5

14 Wing Greenwood 6

19 Wing Comox 8

4 - ANTICIPATED SAVINGS 10

Bulk Storage Tanks 10

Refuelling Trucks 11

Losses Due to Evaporation: Working Losses 11

Losses Due to Evaporation: Standing Losses 13

Vapour Control Systems 13

Reduced Manpower for Fuel Servicing 14

Aircraft Maintenance Costs 14

5 - OPERATIONAL IMPACT 15

Operational Requirements 15

Operational Impact Assessment 16

CF-18A 17

CP-140 Aurora 20

KC-130 Hercules 24

Additional Operational Considerations 28

6 - SAFETY, HEALTH AND ENVIRONMENTAL CONSIDERATIONS 29

7 - SUPPLY AND AVAILABILITY 30

8 - CONCLUSIONS 31

Increased Cost From Purchasing JP-8 31

Anticipated Savings 32

Operational Impact 32

9 - RECOMMENDATIONS 33

REFERENCES 34

EXECUTIVE SUMMARY

1. This study compares the quantitative and qualitative factors associated with the conversion to JP-8 aviation turbine fuel for Canadian Forces (CF) land-based aircraft. The potential economic impact of conversion is studied in the following areas: expected price differential between JP-4 and JP-8 (paras. 8–26)[1]; fuel storage and transportation from refineries to Air Command Wings (paras. 27–45); aircraft maintenance costs (paras. 46–48); and operational impacts (paras. 49–73). Some of the qualitative factors associated with the conversion to JP-8 included in this study are: safety, health and environmental considerations (paras. 74–79); and the supply and availability of JP-8 (paras. 80–82).

2. For this study, the above factors were analyzed for four separate bases and for three different aircraft types. The bases under study include 4 Wing Cold Lake, 8 Wing Trenton, 14 Wing Greenwood and 19 Wing Comox. The different aircraft types studied include the CF-18A (Hornet), the CP-140 (Aurora) and the KC-130 (Hercules). The most important results of this study are summarized below.

Increased Cost from Purchasing JP-8

3. Depending on the purchase price of JP-8, the total increased cost from purchasing JP-8 over JP-4 varies from a savings of $40,000 to a cost increase of $10.91M. However, based on the average cost of JP8 of $0.293/L ($0.260/L for 4 Wing Cold Lake; see para. 85), the cost increase for purchasing JP-8 is approximately **$2.75M** for all four Wings.

Anticipated Savings and Net Loss

4. Anticipated savings from JP-4 to JP-8 conversion are as follows:

a.	Fuel vapour purging of bulk storage tanks:	$8000. (accrued every 3–5 years)
b.	Losses due to evaporation (Working Losses):	$40,000. (accrued annually)
c.	Losses due to evaporation (Standing Losses):	$120,000. (accrued annually)

Therefore, the total anticipated annual recurring savings from JP-4 to JP-8 conversion is approximately **$0.162M.**

[1] Paragraph numbers refer to main report.

5. Also, as a result of conversion, a *possible* one time savings of approximately $750,000 (U.S.) ($975,000 CAN) would be achieved if, due to stricter environmental regulations, Canadian emissions standards forced the CF to lower its fuel vapour emissions into the atmosphere. This cost to the department does not presently exist but may be incurred if JP-4 remained the primary aviation turbine fuel. It was also determined that there will be no savings realized in fuel servicing operations or aircraft maintenance costs due to a conversion.

6. Therefore, it is concluded that a conversion from JP-4 to JP-8 would result in an annual net loss to the CF of approximately **$2.6M**. However, this loss is largely attributed to the sensitivity in the purchase price and the cost increase incurred at 4 Wing Cold Lake. Since 4 Wing purchases such large quantities of jet fuel, a difference of $0.01/L in the purchase price translates into a $1.0M cost increase. If a much lower price than the average JP-8 price of $0.293/L can be acquired, then the cost increase, and the net loss to the CF, would be much less.

Operational Impact

7. The results of this study show substantial gains in operational performance using JP-8 instead of JP-4. These gains are, however, difficult to quantify and are not included in any net savings.

8. For the CF-18A, a higher density fuel not only extends the operating range from 7%–18% (scenario dependent) but in certain cases allows the mission requirements to be fulfilled which would not have been possible if JP-4 had been used. The CP-140 can add approximately 41 ± 3 minutes to fulfilling its ASW role or extending its operating range approximately 113 ± 4 nm beyond its normal limits. For the KC-130, the impact is marginal. Use of JP-8 increases the range by 30–50 nm or loiter time by 16–20 minutes. However, any refueled fighter aircraft are able to patrol over longer distances and for longer times, thereby decreasing the number of missions and the number of aircraft needed to patrol while increasing the patrol area.

Operational Considerations

9. Various studies concerning altitude relight and low temperature starts have concluded that operational or flight safety limitations apply to JP-8 use for some CF land-based aircraft not included in the analysis of this report. They are:

a. CH118/135/136 Fleets: Use of JP-8 reduces the cold weather start-up capability of these helicopters. Helicopter start-ups are limited to -18°C instead of -30°C for the CH118 and

to -30°C instead of -40°C for the CH135/136. Note: phase out of these helicopter fleets and replacements by the CH146 is scheduled for completion by January 1998.

b. CH146 Fleet: Use of JP-8 reduces cold weather start-up to -30°C instead of -40°C with JP-4.

10. Additionally, JP-8 is known to increase coking or carboning of the fuel nozzles and combustion chambers thereby increasing the requirements for more aircraft maintenance.

Safety, Health and Environmental Considerations

11. Low volatile fuels such as JP-8 are in general safer than high volatile fuels (JP-4) at fuel temperatures most generally experienced in aircraft and ground operations. JP-8 essentially has no vapour pressure at ambient conditions thereby making it safer to handle than JP-4.

12. As a result of JP-8's lower volatility, the following is concluded in terms of aircraft operations:

a. JP-8 reduces the possibility of in-flight and post-crash fires;
b. JP-8 is less susceptible to fire and explosion induced by gunfire; and
c. JP-8 provides an overall superior aircraft combat survivability posture compared to JP-4.

13. Aside from the safety considerations, there are also health considerations involved in the conversion from JP-4 to JP-8. With the conversion to JP-8, there will be less respiratory threat from benzene, neurotoxicity will be decreased and bone marrow toxicity will be decreased. There will, however, be a higher threat from skin absorption.

14. Conversion to JP-8 would virtually eliminate the raw hydrocarbon vapour emissions from storage tanks and handling associated with JP-4. The oxides of nitrogen are expected to be the same for JP-4 and JP-8 since nitrogen oxide concentration depends on cycle temperature and not on fuel properties. Some of the downfalls resulting in a conversion from JP-4 to JP-8 include increased smoke emissions from aircraft engines and an increase in unburned hydrocarbon and carbon monoxide emissions.

15. Although no environmental legislation exists on the maximum sulfur content of aviation fuel when burned, the sulfur content of JP-8 (0.1% – 0.3% per volume) is smaller than that of JP-4 (0.1% – 0.4% per volume). According to Esso Imperial Oil, legislation enforcing low sulfur fuels could come into place. Therefore, the conversion from JP-4 to JP-8 would also be more environmentally friendly.

Supply and Availability

16. The cost advantage previously associated with JP-4 has been disappearing gradually due to reducing JP-4 refinery production in Canada. It is expected, possibly in the near future, that the cost advantage will then belong to JP-8 because there will be less competition for supplying JP-4.

17. Despite the fact that only 8% of a barrel of crude is suitable for refining into JP-8 fuel, there is sufficient stocks of JP-8 on the world market to meet any increase in demand brought about as a result of conversion.

18. Interoperability with NATO nations and world-wide availability of JP-8 is a significant factor in considering standardization to JP-8. There is virtually *no* JP-4 fuel available in Europe. This conversion would bring Canada one step closer to the US concept of "one fuel for the battlefield" and its logistic multiplier effect.

Recommendations

19. Based on the results of this study, the following is recommended.

a. Complete engineering studies be undertaken on the refuelling trucks to determine their reaction to JP-8.

b. More accurate costs for production and implementation into service should be determined.

c. Although little or no conversion is required for most aircraft types to use JP-8, a maintenance review should be conducted for related fuel systems, especially addressing coking problems noticed in the CH113 (Labrador) aircraft using JP-8.

d. It is recommended that conversion to JP-8 take place provided that operational limitations with regards to cold weather start-up for the CH146 (Griffon) be addressed.

THE ECONOMIC AND OPERATIONAL IMPACT OF JP-4 TO JP-8 CONVERSION

1 - INTRODUCTION

1. The use of JP-4 aviation turbine fuel as the standard for military air operations dates back to the late 1960's. As a result of combat losses directly related to fuel fires or explosions, the United States Air Force (USAF) initiated an evaluation of a more combat safe fuel. JP-8, which is essentially commercial Jet A-1 with fuel system icing inhibitor (FSII) and corrosion inhibitors added, was selected for further testing in 1968 [1].

2. In June 1974, NATO nations agreed that the preferred military fuel should be JP-8 and conversion should proceed when operational limitations and supply considerations had been overcome. At the 1976 NATO Defense Ministers Conference, Canada agreed that all NATO land-based aircraft would convert to the use of a standard fuel type. In May 1987, Canada committed itself to the use of JP-8 as its standard fuel type in Europe. All NATO allies, except for Turkey, have converted to JP-8. Australia, New Zealand, the United Kingdom and France have been using JP-8 for more than 20 years[1].

3. In response to the above NATO fuel standardization initiatives and possible economic savings, Air Command is considering the adoption of JP-8 as the single fuel for land-based aircraft.

4. This study compares the quantitative and qualitative factors associated with the conversion to JP-8 for Canadian Forces (CF) land-based aircraft. The potential economic impact of conversion is studied in the following areas: expected price differential between JP-4 and JP-8; fuel storage and transportation from refineries to Air Command Wings; Base fuel systems; aircraft maintenance costs; and operational impacts. Some of the qualitative factors associated with the conversion to JP-8 included in this study are: safety and health considerations; environmental considerations; and the supply and availability of JP-4 and JP-8.

5. For this study, the above factors were analyzed for four separate bases and for three different aircraft types. The bases under study include 4 Wing Cold Lake, 8 Wing Trenton, 14 Wing Greenwood and 19

[1] The CC130 fleet has been using JP-8 fuel operationally for over five years on overseas flights. The USAF is completing its conversion to JP-8 this year for CC130s. Within Canada, Jet A-1 is often used at commercial airports in lieu of military JP-4.

Wing Comox. The different aircraft types studied include the CF-18A (Hornet), the CP-140 (Aurora) and the KC-130 (Hercules).

2 - FUEL DESCRIPTIONS AND PROPERTIES

6. JP-4 fuel (NATO Code 'F-40') is a wide-cut, gasoline type, aviation turbine fuel. It is essentially a 50:50 mixture of heavy naphtha and kerosene. JP-8 fuel (NATO Code 'F-34') is basically Jet A-1 fuel (a kerosene based aviation turbine fuel) plus three military additives. These additives are: fuel system icing inhibitor, corrosion inhibitor/lubricity improver additive, and static dissipater additive [2].

7. The primary differences between JP-4 and JP-8 include volatility, density and the volumetric heat of combustion. Table 1 lists important fuel properties of JP-4 and JP-8.

Property	JP-4	JP-8
Density, kg/m^3	750 - 801	774 - 839
Density (Normal Average) (lb/gal)	6.34	6.71
Freezing Point, °C	-58	-47
Flash Point, min, °C	-29	+38
BTU's Per gal, min	115,000	119,000
Vapour Pressure, KPA (range)	14 - 21	0
Initial Boiling Point, °C (range)	142	329

Table 1. Comparison of JP-4 and JP-8 Fuel Properties

3 – FUEL COSTS

8. The cost differential between JP-4 and JP-8 is important to consider when determining whether or not a conversion is economically feasible. Generally, the cost per litre of JP-8 is higher because it uses more expensive components of the crude oil during refining and because it is more dense and contains more energy per unit volume.

9. It is difficult to estimate the costs incurred from a conversion because cost data for both types of fuel is not available for every base. The fuel contracts used for this study only contained the cost per litre of the fuel that is currently being used at that particular base [3]. Therefore, in order to perform the analysis, some assumptions had to be made. For example, an average JP-8 price had to be estimated for those bases under study where this cost figure was unavailable. In order to calculate an average cost figure

for JP-8, the costs per litre of JP-8 fuel were averaged over the bases where JP-8 prices were available. It should be noted that some of the cost figures for JP-8 had to be excluded from this calculation. One JP-8 price was not included because the terms of the contract specified that the fuel be picked up from the refinery, thus, the cost did not include any delivery charges and was significantly lower than the other costs. Another cost figure was not included in the average calculation solely because the price was much higher than the others. This particular contract was for a very small volume of fuel and the higher price is most likely attributed to this factor. The calculated approximate average price for JP-8 is $0.293/L.

10. Since the current fuel contracts [3] contained a JP-8 price for CFB Comox but a JP-4 price was unavailable, an average cost figure for JP-4 was required. The same steps were taken in determining an average cost figure for JP-4 as they were for JP-8, including the omission of some cost figures for similar reasons. The calculated approximate average price for JP-4 is $0.260/L.

11. These average prices were used to determine the cost increase of purchasing JP-8 instead of JP-4 at the bases under study. This was done by:

a. varying the amounts of JP-4 usage and calculating the associated costs of the fuel using the prices in the contracts;

b. determining the JP-8 volume equivalence of the JP-4 volume. The associated costs of the JP-8 volume were calculated using a range of prices where the calculated approximate average price lies somewhere in the middle of the range; and

c. subtracting the JP-4 cost from the JP-8 cost resulting in the relative cost increase of using JP-8.

12. For the analysis of CFB Comox, however, the JP-8 prices were listed in the contracts and the JP-4 prices were unavailable. Therefore, with the exception that the JP-4 fuel prices were being varied and not the JP-8 prices, the procedure remained the same. The results of the fuel cost analysis for the four bases are contained in the following sections.

4 Wing Cold Lake

13. 4 Wing Cold Lake currently has a contract with Petro Canada to supply a maximum quantity of **145 Million litres of JP-4 at a unit price of $0.2293/L.**

14. Since the JP-8 prices are unavailable for this base, a range of JP-8 prices of $0.260/L – $0.320/L was used in order to properly represent the cost increase of purchasing JP-8 instead of JP-4. These values were chosen because the calculated approximate average price lies somewhere between these values thus accounting for any error that was incurred in the calculation of the average. Figure 1 shows the resulting cost increases of purchasing JP-8 instead of JP-4 for a range of JP-8 volumes and prices.

15. Over the past year (August 1994 - July 1995) CFB Cold Lake used approximately 100 Million litres of JP-4 fuel at a cost of approximately $23 Million. Taking into consideration the higher density of JP-8 fuel, 100 Million litres of JP-4 is approximately the same as 94.5 Million litres of JP-8. Assuming an average JP-8 price of $0.293/L and a JP-8 fuel volume of 94.5 Million litres, it is seen from Figure 1

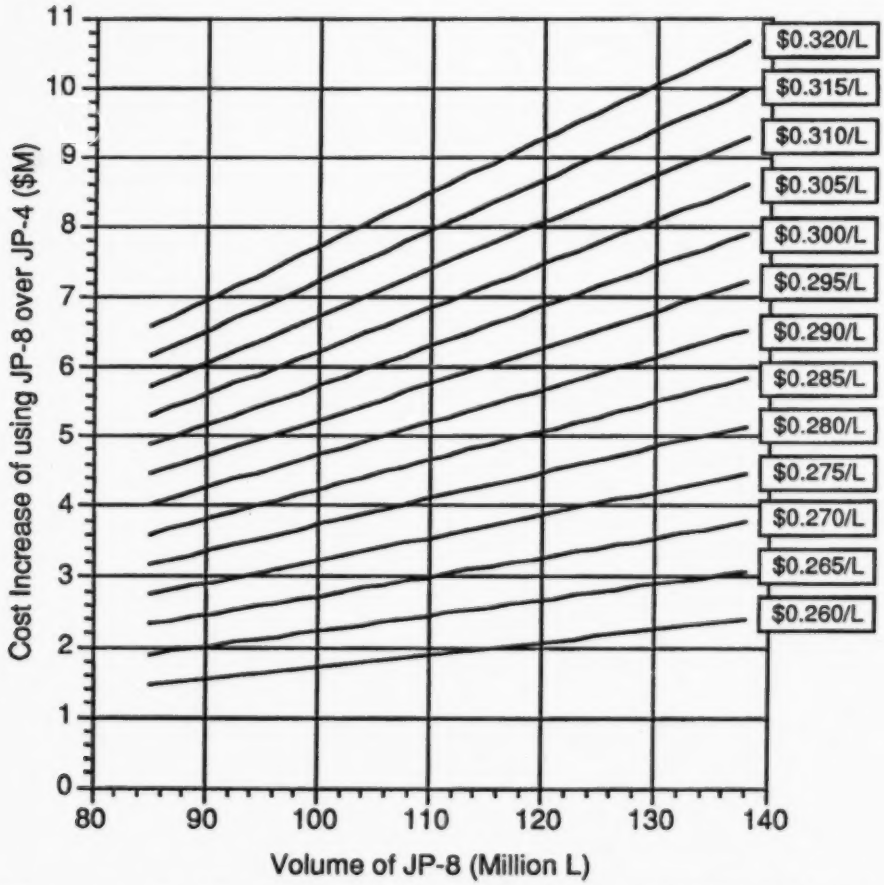

Figure 1. Cost Increase of JP-8 Fuel Purchases at CFB Cold Lake (Based on JP-4 price of $0.2293/L)

that the cost increase of purchasing JP-8 amounts to approximately $4.8 Million. This is a very large increase but it should be noted that the per litre cost increase is also very large. The price is increasing from $0.2293/L to $0.293/L, a difference of $0.0637/L. However, the JP-4 price at this base is significantly lower than those at the other bases under study (as much as $0.0447/L) and is $0.0307 less than the average cost of JP-4. Therefore, it is assumed that JP-8 prices would also be much less than those at the other bases and the price figure used here ($0.293/L) is most likely on the high side. If 4 Wing is able to acquire JP-8 at the average cost of JP-4 ($0.26/L; and $0.033/L less than the average cost of JP-8), then the cost increase would be approximately $1.6M. Therefore, Figure 1 will serve only to illustrate the associated cost increase in the purchase of fuels at 4 Wing and the reader should not be mislead by the magnitude of the increases in costs.

8 Wing Trenton

16. 8 Wing Trenton currently has a contract with Shell Canada to supply a maximum quantity of **50 Million litres of JP-4 at a unit price of $0.2740/L.**

17. For the analysis of CFB Trenton, a range of JP-8 prices of $0.260/L to $0.320/L was also used to properly represent the cost difference between purchasing JP-8 instead of JP-4. Figure 2 shows the resulting cost increases of purchasing JP-8 instead of JP-4 for a range of JP-8 volumes and prices.

18. As illustrated in Figure 2, a conversion to JP-8 at CFB Trenton does not necessarily increase their fuel cost. If JP-8 prices at this base are approximately $0.290/L, then the base will break even, i.e. no additional costs will be incurred to them nor will they save money. If the JP-8 prices rise above $0.290/L, CFB Trenton will start to see cost increases, but if the JP-8 price stays below this value then they will actually save money from a conversion.

19. Over the past year (August 1994 - July 1995) CFB Trenton used approximately 39 Million litres of JP-4 fuel at a cost of approximately $10.7 Million. The JP-8 equivalent to this amount of JP-4 is approximately 36.8 Million litres. From Figure 2, assuming a JP-8 volume of 36.8 Million litres, a $0.320/L price would result in a cost increase of approximately $1.1M. On the other hand, a $0.260/L price would result in a net savings of approximately $1.1M. These figures show that it is very difficult to determine exactly what effect a fuel conversion will have on the cost of fuel purchases; costs could increase or decrease. However, the $1.1 Million dollar cost increase can be said to be the highest cost increase that

would ever be expected to be incurred since the price of the JP-8 fuel at this base would likely be less than $0.320/L. An average JP-8 cost of $0.293/L would result in a cost increase of approximately $0.12M.

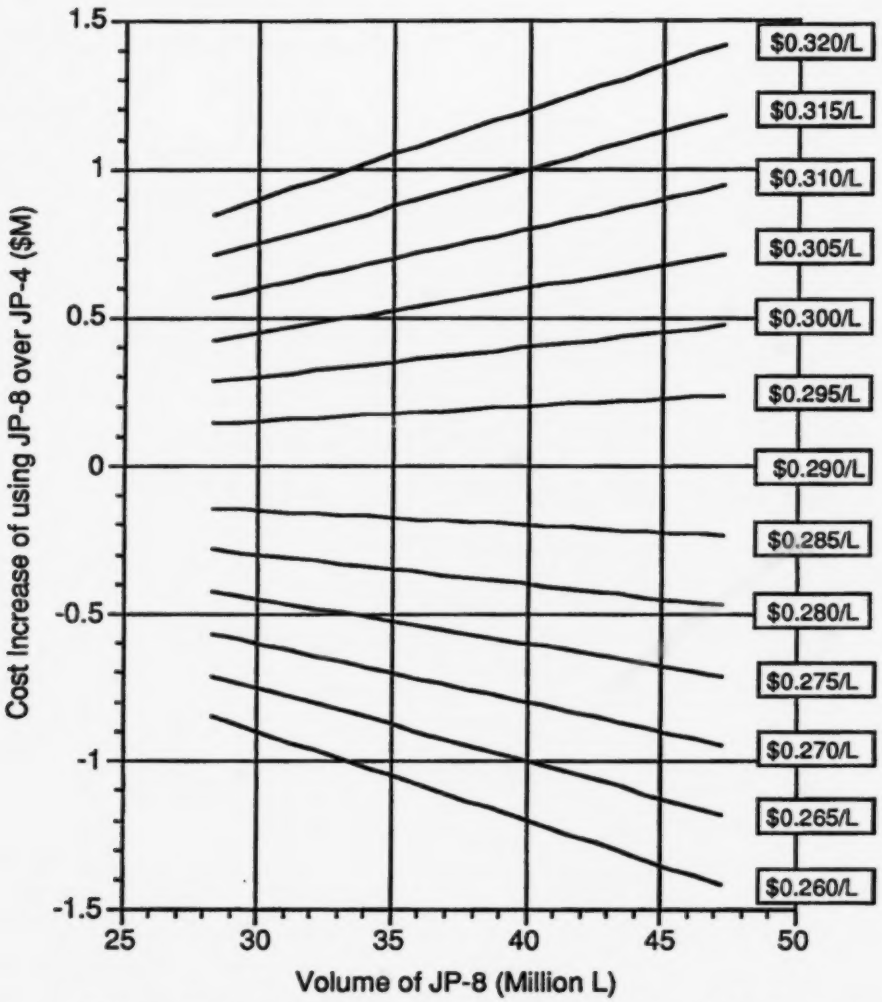

Figure 2. Cost Increase of Fuel Purchases at CFB Trenton (Based on JP-4 price of $0.2740/L)

14 Wing Greenwood

20. 14 Wing Greenwood currently has a contract with Imperial Oil to supply a maximum quantity of **46 Million litres of JP-4 at a unit price of $0.2616/L.**

21. For the analysis of CFB Greenwood, a range of JP-8 prices of $0.260/L to $0.320/L was also used to properly represent the cost increase of purchasing JP-8 instead of JP-4. Figure 3 shows the resulting cost increases of purchasing JP-8 instead of JP-4 for a range of JP-8 volumes and prices.

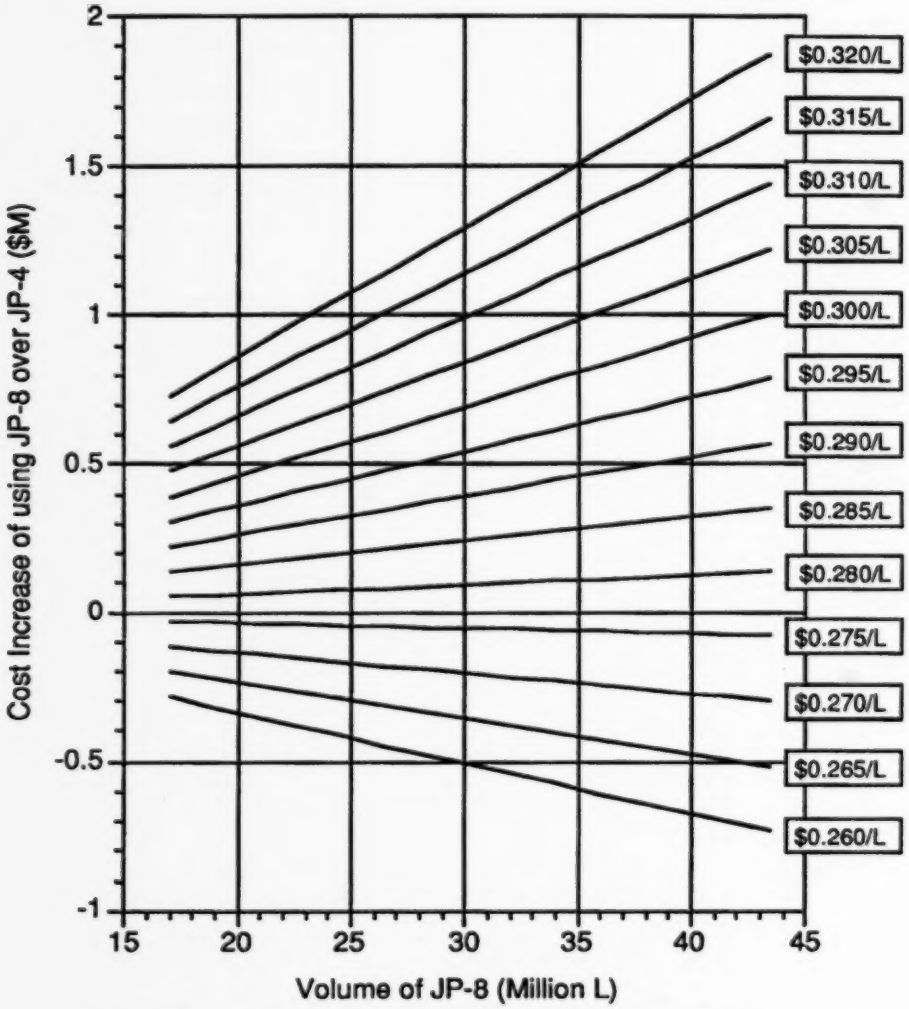

Figure 3. Cost Increase of Fuel Purchases at CFB Greenwood (Based on JP-4 price of $0.2616/L)

22. Over the past year (August 1994 - July 1995) CFB Greenwood used approximately 35 Million litres of JP-4 fuel at a cost of approximately $9.2 Million. The JP-8 equivalent to this amount of JP-4 is approximately 33.1 Million litres. From Figure 3, assuming a volume of 33.1 Million litres, a $0.320/L price would result in a cost increase of approximately $1.43M, and a $0.260/L price would result in a savings of approximately $0.55M. The cost increase of $1.43M is fairly high and would probably not be incurred since a JP-8 price of $0.320/L, resulting in a price increase of $0.0584/L (increase from $0.2616/L), is very unlikely. An average JP-8 cost of $0.293/L would result in a cost increase of approximately $0.53M.

19 Wing Comox

23. 19 Wing Comox currently has a contract with Imperial Oil to supply a maximum quantity of **30 Million litres of JP-8 at a unit price of $0.2979/L.**

24. Since the JP-4 prices are unavailable for this base, a range of JP-4 prices of $0.240/L to $0.280/L was used in order to properly represent the cost increase of purchasing JP-8 instead of JP-4. Figure 4 shows the resulting cost increases of purchasing JP-8 instead of JP-4 for a range of JP-8 volumes and JP-4 prices.

25. It should be noted that only JP-8 prices were available for CFB Comox in the fuel contracts because this base has already started conversion to JP-8 due to the unavailability of JP-4. Once the JP-4 fuel in the tanks is used up, issuing of JP-8 fuel will begin and JP-8 will then be the main fuel used at this base.

26. Over the past year (August 1994 - July 1995) CFB Comox used approximately 24 Million litres of JP-4 fuel. The JP-8 equivalent to this amount of JP-4 is approximately 22.7 Million litres. Assuming JP-4 prices of $0.280/L and $0.240/L and a volume of 22.7 Million litres, the potential cost increase in fuel purchases, as seen in Figure 4, range from $0.04M to $1.0M respectively. The latter cost figure is fairly high and would probably not be incurred since a JP-4 price of $0.240/L at this base is very unlikely because it is too low. However, based on the average JP-4 price of $0.260/L, the cost increase due to conversion would be approximately $0.5M.

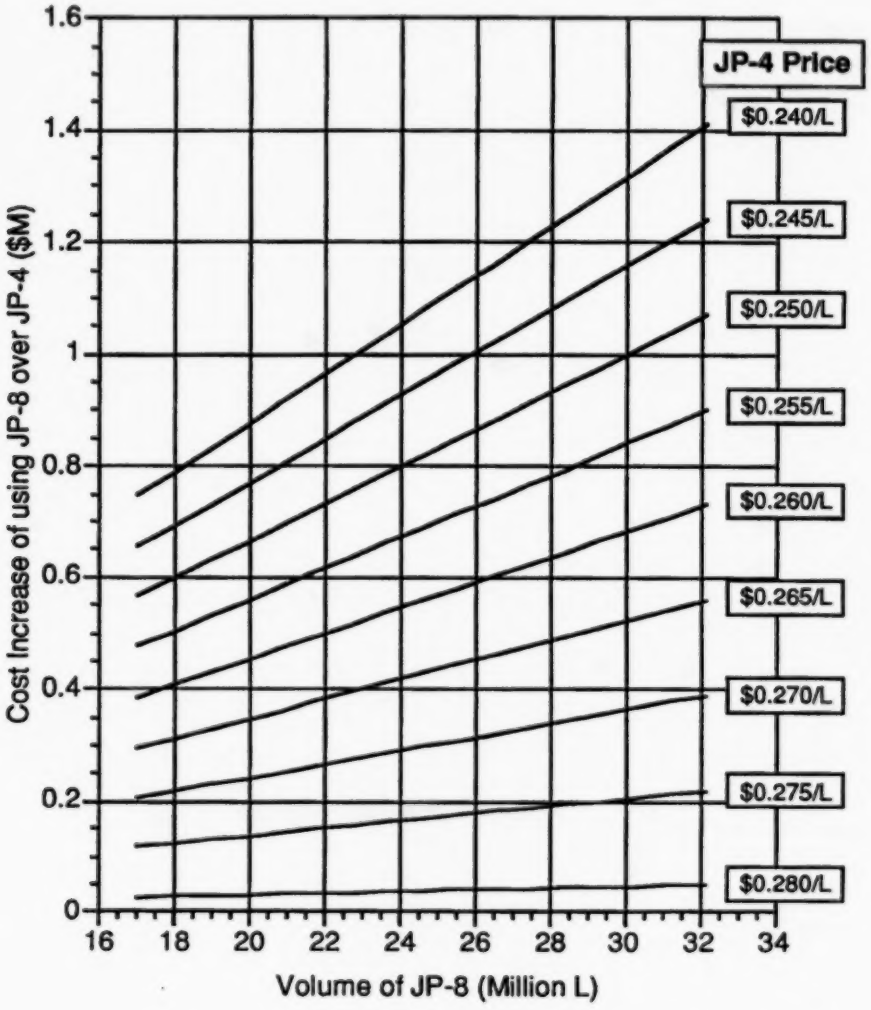

Figure 4. Cost Increase of Fuel Purchases at CFB Comox (Based on JP-8 price of $0.2979/L)

4 - ANTICIPATED SAVINGS

Bulk Storage Tanks

27. Independent of fuel type stored, bulk storage tanks must be cleaned, inspected and repaired every 3 to 5 years (every 3 years for tanks without epoxy coating and every 5 years for tanks with epoxy coating). Any tank maintenance procedure requires four people; 1 WFE (Water Fuel Environment) technician, 1 qualified tank cleaner and 2 additional persons to monitor purging operations and safety procedures.

28. Prior to any bulk storage tank maintenance, all JP-4 fuel must be removed and the fuel vapours purged using air compressors at least 2 hours before the tank can be entered. It takes 2.5 to 3 hours to purge the JP-4 fuel vapours from most of the tanks before the LEL (Lower Explosive Limit) standards of 20 percent are met. It takes on average of 1-3 hours to clean the tank. Larger tanks can take up to 16 hours [5].

29. With the low vapour pressure of JP-8, there would be little or no need for purging of fuel vapours before bulk storage tank maintenance can proceed [4]. Table 2 provides information on the number and size of the storage tanks, and estimates vapour purging times. If four people are present during purging operations and based on personnel cost of approximately $20/hour, the 100 estimated hours dedicated to fuel vapour purging at these four bases alone would save approximately $8000 once every 3 to 5 years.

CFB	Number of Bulk Storage Tanks	Tank Capacity (L)	Purging Time Per Tank (Hrs)	Est. Vapour Purging Time (Hrs)
4 Wing Cold Lake	4 (on base)	890,000	3	12
	3 (Strategic Air Command Site)	4,400,000	16	48
8 Wing Trenton	3	959,927	3	9
14 Wing Greenwood	1	2,750,435	7.5	7.5
	2	891,652	3	6
	1	217,708	2.5	2.5
19 Wing Comox	5	909,218	3	15
		Total:		**100 hrs.**

Table 2. Number and Size of Bulk Storage Tanks

30. Another aspect of the bulk storage tanks which needs to be discussed is the effect that the JP-8 fuel will have on the rubber seals and fittings on the tanks. USAF members have advised (unofficially) that the seals will react very negatively to a switch from JP-4 to JP-8 and that severe leakage will occur [6]. Comox received its first shipment of JP-8 on 29 June 1995 and a second shipment on 9 August 1995 and JP-8 is currently contained in 4 of the 5 tanks available. As of this date, there have been no problems with leakage or any other negative reactions with any of the seals or fittings on these four tanks [7]. Therefore, it is unknown if any negative reactions on the storage tank seals will occur from the conversion.

Refuelling Trucks

31. According to Reference 8, the Victaulic couplings used in all of the flexible joints of the refuelling system will not have to be replaced and will operate fine with JP-8 fuel. Also, the seals on the tank lids and the vents will not have to be changed if a conversion to JP-8 takes place. However, the seals on the 4 inch internal emergency valve (Part # F-614-A) would most likely need to be changed.

32. Estimating the costs of replacing these seals in the refuelling trucks is difficult for several reasons. Firstly, it is undetermined how many of the seals would need to be replaced. Secondly, considering the large number of seals in the trucks, it would require large amounts of labor in order to replace them. However, Reference 8 states that the leakage of the JP-8 fuel will be very minor and will most likely not exceed the accepted limits. In order to determine if in fact the use of JP-8 will have a negative effect on the refuelling trucks, it is recommended that JP-8 be tested in the trucks by circulating the fuel every day for one week. If problems are to occur with the new fuel they would be realized within this time.

33. The reaction of a fuel conversion from JP-4 to JP-8 has an unknown effect on refuelling vehicles. If negative effects were to occur, they would most likely occur in the seals and movable joints of the refuelling system in the trucks.

Losses Due to Evaporation: Working Losses

34. For the bases under consideration in this study, the fuel transportation methods are tank cars for 4 Wing and tank wagons for 8 Wing and 14 Wing. Barges are used for fuel shipments to 19 Wing.

35. During transport from the refinery to the respective bases, the fuel undergoes at least one fill/drain cycle. With JP-4, each fill/drain cycle results in the venting and loss of fuel vapour when the empty tanks

at the bases are refilled. These losses are termed "Working Losses" [4]. For each fill/drain cycle the amount of JP-4 lost due to evaporation is estimated to be 0.06 percent of the amount being transferred. With the conversion from JP-4 to JP-8, evaporation loss (and the consequential cost) from fill/drain cycles would be eliminated since JP-8 fuel would not evaporate during fill/drain procedures due to its higher density and lower volatility.

36. Figure 5 shows the cost of fuel lost due to evaporation during a fill/drain cycle. The cost of lost fuel is plotted against the percent of the maximum volume of JP-4 used, where the maximum volume of JP-4 used is the maximum allowable volume that can be supplied from the refinery to the base as stated in the fuel contracts. The maximum quantity that can be supplied to each base is 145 Million Litres per year @ $0.2293/L for CFB Cold Lake, 50 Million Litres per year @ $0.2740/L for CFB Trenton, 46 Million Litres per year @ $0.2616/L for CFB Greenwood and 30 Million Litres per year @ an estimated $0.26/L for CFB Comox. These maximum volumes and the unit prices ($/L) of the fuels were obtained from the 1995 Fuel Contracts [3].

37. As expected, when the amount of JP-4 which is being supplied by the refinery is increased, the cost of fuel lost due to evaporation also increases. As shown in Figure 5, if the maximum fuel supply was used for each base, approximately $40,000 worth of fuel would be lost due to evaporation during its delivery alone.

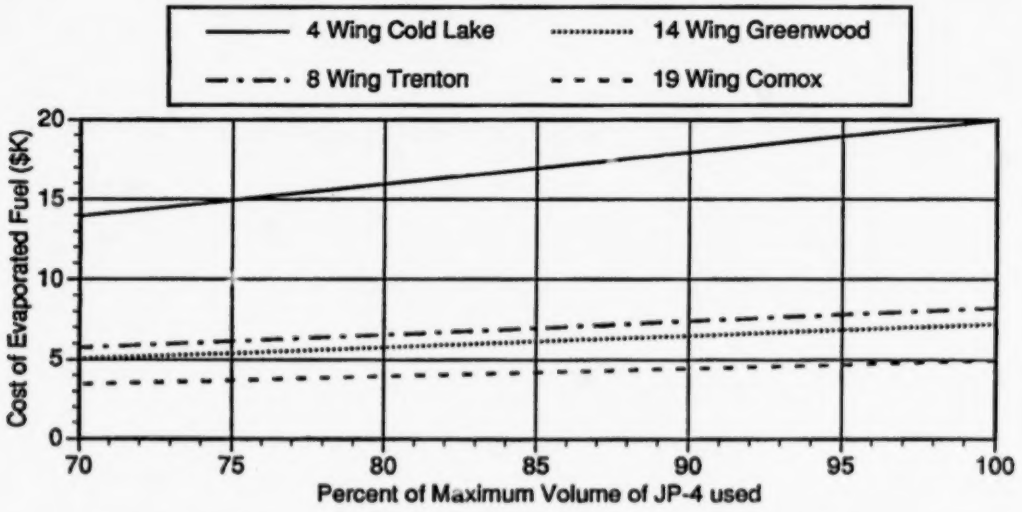

Figure 5. Cost of Evaporated Fuel due to 1 Fill/Drain Cycle

Losses Due to Evaporation: Standing Losses

38. "Standing Losses" are due to evaporation from the bulk storage tanks themselves. Appendix A of Reference 4 estimates, for a crude oil with a Reid vapour pressure of 2 psi, a loss at 33 percent of the standing loss for gasoline (5%), i.e., 1.67%. This loss rate was assumed for JP-4 which has a Reid vapour pressure of between 2 and 3 psi.

39. Using the data in Table 2 and a standing loss rate of 1.67 percent per year, the fuel loss on each base due to evaporation and the corresponding estimated recoverable costs are given in Table 3.

CFB	No. of Tanks	Total Tank Capacity (L)	Standing Loss (L)	$/L of JP-4	Recoverable Cost/Year (Est.) ($)
4 Wing Cold Lake	7	16,760,000	279,892	0.2293	64,179
8 Wing Trenton	3	2,879,781	48,092	0.2740	13,177
14 Wing Greenwood	4	4,751,447	79,349	0.2616	20,758
19 Wing Comox	5	4,546,090	75,919	0.2800	21,257
				Total Estimated:	**$120,000**

Table 3. Estimated Recoverable Costs From Standing Losses

Vapour Control Systems

40. Due to strict environmental standards in the United States, the United States Air Force is required to equip their bulk storage tanks with vapour control systems to retard evaporation of JP-4 fuel. With increasing trends towards environmental safety and awareness, it is acceptable to assume that Canada will face the same level of environmental standards as the United States sometime in the near future. If this happens, the Canadian Air Force will be required to equip their bulk storage fuel tanks with vapour control systems.

41. It is estimated to cost between $25,000(US$) and $50,000(US$) to equip bulk fuel tanks with floating pans to retard the evaporation of JP-4 fuel [4]. Using an average cost of $25,000 for the smaller tanks, $37,500 for the medium sized tanks (approximately 900,000 L capacity) and a cost of $50,000 for the larger tanks, the cost of implementing this type of vapour control system at the four study bases would cost approximately $750,000(US$).

42. The above costs of implementing vapour control systems only pertains to the use of JP-4 fuel. If JP-8 becomes the primary Air Force fuel, floating pans in the bulk tanks will not be required due to JP-8's much lower evaporation rate. Therefore, this cost can be considered a cost avoidance attributable to the fuel conversion.

43. It should be stressed that the above costs will only be incurred with JP-4 if the Canadian emission standards become more strict and Air Command is required to lower its fuel vapour emissions into the atmosphere.

Reduced Manpower for Fuel Servicing

44. Three persons are normally present during any aircraft refuelling operation. They consist of 1 Airframe Tech, 1 person operating the fuel flow from the truck and 1 person standing by with a fire extinguisher in case of an accident or fire. Some of the larger aircraft which have more than one vent and multiple fuel nozzle connections often require more than the standard three people present in order to perform a safe refuelling.

45. According to the USAF study [4], since the volatility of JP-8 is much less than that of JP-4, refuelling personnel could be reduced and the safety standards could be relaxed with JP-8. However, this is not believed to be the case for Canada if a conversion was implemented. Safety standards would not be relaxed and the same number of persons would be needed during aircraft refuelling. Therefore, there will be no savings realized in this area.

Aircraft Maintenance Costs

46. Prior to any aircraft maintenance procedure, there are steps taken to ensure that the aircraft is safe to work in and around. For the procedures involving any part of the aircraft fuel system or fuel tanks, it is required that the aircraft tanks be drained of all fuel and then purged with air, to remove fuel vapours, for a period of time until the Lower Explosive Limit (LEL) of the fuel is reached.

47. Before any purging operations can be performed, the aircraft must be grounded, the batteries must be disconnected, a sign on aircraft Door 9 must be installed prohibiting the energizing of the aircraft electrical system, and a safety perimeter around the aircraft must be roped off. Once this is done, the ventilation procedures are performed until the LEL reaches 10% or less, and there is at least 19.5% of

oxygen present in the tanks [9]. It can take anywhere from 18-24 hours of purging until the LEL reaches the required level of 10%. During maintenance procedures on the fuel systems, continuous readings of the LEL and oxygen levels must be taken to ensure that the levels meet the required minimums. If the LEL exceeds 10%, all work must stop immediately and shall not resume until acceptable levels are restored.

48. In Reference [4] it was stated that, with the use of JP-8 fuel instead of JP-4, the purging operations of the aircraft tanks prior to maintenance was unnecessary and a savings would therefore result due to a conversion. This does not apply to the CF. With the use of JP-8 fuel, the ventilation and purging of aircraft fuel systems is still necessary before any work can be performed on the fuel system or fuel tanks [10]. Therefore, in the conversion from JP-4 to JP-8, there would not be any cost savings realized in the aspect of aircraft maintenance procedures involving the fuel systems or fuel tanks of aircraft.

5 - OPERATIONAL IMPACT

Operational Requirements

49. For any particular mission profile and weapon/aircraft configuration, the maximum operating range and time-on-station (TOS) of certain CF aircraft are limited by the volume rather than the weight of fuel that the aircraft can carry. This factor is most significant for maritime surveillance operations as current aircraft are heavily tasked to cover the coastlines of Canada. Since the primary combustion process in the gas turbine engine involves burning a given weight of fuel in a given weight of air, it stands to reason that a higher density fuel such as JP-8 would have a positive operational impact on the ability of maritime patrol aircraft limited by fuel volume to fulfill more strenuous missions.

50. Other operational factors need also be considered. The CF-18 tactical fighter is required to operate extensively in the far northern regions of Canada. Missions are extended by virtue of the territory which must be covered. The consequences of depletion of fuel are catastrophic due to the extreme weather conditions encountered and distances from relief centers. The ability to carry an additional approximate 6% of energy could have significant operational and flight safety benefits for the CF-18 aircraft.

51. Closely tied to fighter operations in the previously mentioned, and in many other operational theatres, is the conduct of Air-to-Air refuelling (AAR). Canada has an extensive AAR mission requirement. Tanker range and endurance would assuredly benefit as would the amount of energy which could be

transferred to the supported fighter aircraft. Potentially more aircraft could be refueled with a fixed energy load, or conversely a fixed number of aircraft could be refueled with a greater amount of energy.

Operational Impact Assessment

52. The operational impact of a conversion from JP-4 to JP-8, i.e., using an aviation turbine fuel with 5.8% more volumetric energy content relative to JP-4, was examined for three different Canadian Forces aircraft: the CF-18A (Hornet) [11], the CP-140 (Aurora) [12] and the KC-130 (Hercules) [13]. Various mission profiles and weapon/aircraft configurations were simulated for each aircraft in all phases of flight. Expended fuel was accounted for at the end of each phase such that the aircraft would land with its minimum IFR (Instrument Flight Rules) reserves. In this manner, operating range and TOS may be varied independently so as to determine the operational impact due to the increase in energy content realized through the conversion of JP-4 to JP-8.

53. For each aircraft, a mission profile was examined which allows it to operate at a certain range from its home base. After a long-range cruise it may either dash to the target and unload its stores (CF-18A), loiter-on-station in an ASW (Anti-Submarine Warfare) role (CP-140), or loiter-on-station and provide AAR to fighter aircraft (KC-130).

54. Regardless of the operational requirements, each simulation determines the fuel expended at the conclusion of each phase of flight [14]. The different phases of flight are:

a. Start/Taxi/Take-Off;
b. Climb to cruising altitude;
c. Cruise to operating area;
d. Fulfill mission requirements;
e. Cruise to home base;
f. Descend to home; and
g. Approach and landing.

55. All data such as specific range, fuel flow, True Airspeed (TAS) etc. were modelled as polynomials in the appropriate parameter, i.e., aircraft gross weight or time. By varying the cruise range and loiter time and landing with minimum IFR reserves, each simulation provided a straightforward determination of the operational benefit of using JP-8 on fuel volume limited aircraft.

CF-18A

56. Three mission profiles were considered for the CF-18A. Figure 6 illustrates the three profiles used in the analysis. For each profile, there were seven combinations of aircraft configurations and weapons (MK-82 SE Bombs, BL755 Bombs, LAU-5003A/A Rocket Launcher with 10 lb RX warhead and nose cones). Tables 4 to 6 detail the different configurations and store data used in the analysis.

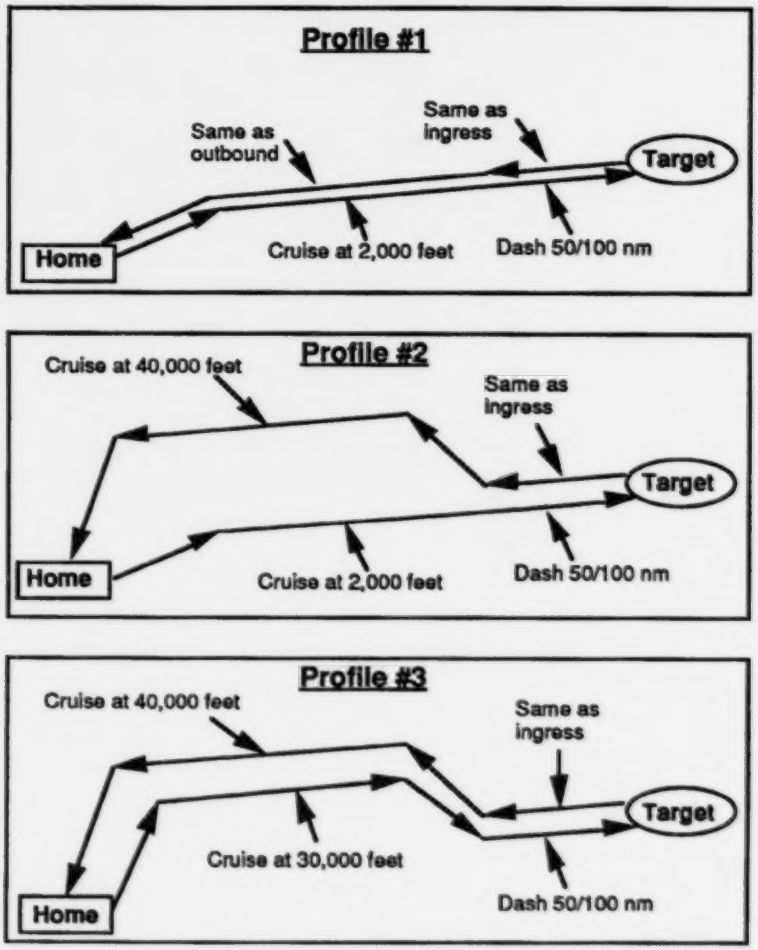

Figure 6. CF-18A Mission Profiles

Conf	Aircraft Station								
	W/T	O/B	I/B	FUS	C/L	FUS	I/B	O/B	W/T
1	AIM-9 (1)	Weapons (2)	Weapons (2)	Clean	330 gal tank	Clean	Weapons (2)	Weapons (2)	AIM-9 (1)
2	AIM-9 (1)	Weapons (2)	330 gal tank	Clean	Weapons (2)	Clean	330 gal tank	Weapons (2)	AIM-9 (1)
3	AIM-9 (1)	Weapons (2)	330 gal tank	Clean	330 gal tank	Clean	330 gal tank	Weapons (2)	AIM-9 (1)

( ) = number of stores

Table 4. CF-18A Configurations

Store	Weight per Store (lbs)	Drag Index
MK-82 SE	565	6.0
BL-755	610	16.8
LAU-5003	530	8.0
330 gal tank	230	10.5/14.5
Pylon	130/273	3.0/7.5
VER	175	9.0

N1/N2 = Centerline/Wing

Table 5. Stores Data

Number of Tanks	JP-4 Fuel (lbs) (Includes Internal Fuel)
1	11,950
2	14,043
3	16,135

Table 6. Usable Fuel

57. The CF-18A Aircraft Operating Instructions (AOI) were used to calculate the range and fuel expended under each profile and configuration [11]. Two results were extracted for the CF-18. First, for each dash distance (50 nm or 100 nm) and fuel type, a radius of action was calculated such that the aircraft landed with remaining fuel in the range: 2000 lbs ≤ fuel ≤ 2042 lbs. Table 7 shows the percent increase in the radius of action as a result of using JP-8 over JP-4. Second, the range and fuel expended under each profile and configuration were calculated for each dash distance using JP-4. The simulation was then run using JP-8 (1.058 x JP-4) and the amount of fuel required to perform the same mission range was calculated. Table 8 shows the decreased JP-8 fuel requirements in order to perform the same mission using JP-8 instead of JP-4.

		Profile #1						Profile #2						Profile #3					
		50 nm Dash			100 nm Dash			50 nm Dash			100 nm Dash			50 nm Dash			100 nm Dash		
Weapons	Con.	JP-4	JP-8	%	JP-4	JP-8	%	JP-4	JP-8	%	JP-4	JP-8	%	JP-4	JP-8	%	JP-4	JP-8	%
MK-82 SE	1	192	208	8	176	192	9	225	246	9	184	206	12	263	292	11	183	213	16
	2	238	256	8	222	241	9	288	313	9	248	274	10	350	383	9	273	308	13
	3	292	313	7	277	298	8	363	391	8	323	353	9	460	499	8	383	423	10
BL755	1	173	187	8	152	166	9	195	214	10	151	171	13	220	248	13	n/a	157	n/a
	3	275	295	7	258	278	8	335	361	8	295	322	9	427	464	9	346	385	11
LAU-5003	1	188	203	8	170	186	9	218	238	9	176	197	12	253	283	12	166	196	18
	3	288	309	7	272	293	8	356	384	8	317	346	9	441	477	8	367	405	10

Table 7. CF-18 Percent Increase in Radius of Action Due to JP-8 Usage

		Profile #1		Profile #2		Profile #3	
		50 nm dashes	100 nm dashes	50 nm dashes	100 nm dashes	50 nm dashes	100 nm dashes
Weapons	Config.	Less Fuel Required (lbs)	Less Fuel Required (lbs)	Less Fuel Required (lbs)	Less Fuel Required (lbs)	Less Fuel Required (lbs)	Less Fuel Required (lbs)
MK-82 SE	1	643	650	613	629	588	616
	2	762	770	714	732	671	704
	3	879	888	811	832	755	792
BL-755	1	636	649	608	630	592	621
	3	880	892	817	840	763	801
LAU 5003	1	645	653	617	632	594	618
	3	874	879	807	824	743	779

Table 8. Reduced JP-8 Fuel Requirements For CF-18A Missions

58. The results shown in Table 7 indicate significant operational improvement when using JP-8. The percent increase in the radius of action varies from a low of 7% to a high of 18%. Even though the difference in the radii of action due to the two fuels increases as the configurations change from 1 to 3, the percent difference decreases. After weapons release, the aircraft is much heavier for configuration 3 than for configuration 1. It may cruise further from home but it will also expend fuel at a faster rate. One significant feature of Table 7 is that under Profile #3 and configuration 1 when armed with BL755 bombs and dashing 100 nm, the operational requirements are not met using JP-4 but are met using JP-8.

59. The results of Table 8 also indicate a significant savings in fuel when using JP-8 over JP-4. In order to complete the same mission using JP-8 instead of JP-4, it is possible to use anywhere from approximately 600 to 900 lbs less fuel. Also, the CF-18A has had no apparent problems using JP-8 after several years of use in Europe and has operated successfully on JP-8 during Desert Shield/Storm.

Conf	Aircraft Station								
	W/T	O/B	I/B	FUS	C/L	FUS	I/B	O/B	W/T
1	AIM-9 (1)	Weapons (2)	Weapons (2)	Clean	330 gal tank	Clean	Weapons (2)	Weapons (2)	AIM-9 (1)
2	AIM-9 (1)	Weapons (2)	330 gal tank	Clean	Weapons (2)	Clean	330 gal tank	Weapons (2)	AIM-9 (1)
3	AIM-9 (1)	Weapons (2)	330 gal tank	Clean	330 gal tank	Clean	330 gal tank	Weapons (2)	AIM-9 (1)

( ) = number of stores

Table 4. CF-18A Configurations

Store	Weight per Store (lbs)	Drag Index
MK-82 SE	565	6.0
BL-755	610	16.8
LAU-5003	530	8.0
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Pylon	130/273	3.0/7.5
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		Profile #1						Profile #2						Profile #3					
		50 nm Dash			100 nm Dash			50 nm Dash			100 nm Dash			50 nm Dash			100 nm Dash		
Weapons	Con.	JP-4	JP-8	%	JP-4	JP-8	%	JP-4	JP-8	%	JP-4	JP-8	%	JP-4	JP-8	%	JP-4	JP-8	%
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LAU-5003	1	188	203	8	170	186	9	218	238	9	176	197	12	253	283	12	166	196	18
	3	288	309	7	272	293	8	356	384	8	317	346	9	441	477	8	367	405	10

Table 7. CF-18 Percent Increase in Radius of Action Due to JP-8 Usage

		Profile #1		Profile #2		Profile #3	
		50 nm dashes	100 nm dashes	50 nm dashes	100 nm dashes	50 nm dashes	100 nm dashes
Weapons	Config.	Less Fuel Required (lbs)	Less Fuel Required (lbs)	Less Fuel Required (lbs)	Less Fuel Required (lbs)	Less Fuel Required (lbs)	Less Fuel Required (lbs)
MK-82 SE	1	643	650	613	629	588	616
	2	762	770	714	732	671	704
	3	879	888	811	832	755	792
BL-755	1	636	649	608	630	592	621
	3	880	892	817	840	763	801
LAU 5003	1	645	653	617	632	594	618
	3	874	879	807	824	743	779

Table 8. Reduced JP-8 Fuel Requirements For CF-18A Missions

58. The results shown in Table 7 indicate significant operational improvement when using JP-8. The percent increase in the radius of action varies from a low of 7% to a high of 18%. Even though the difference in the radii of action due to the two fuels increases as the configurations change from 1 to 3, the percent difference decreases. After weapons release, the aircraft is much heavier for configuration 3 than for configuration 1. It may cruise further from home but it will also expend fuel at a faster rate. One significant feature of Table 7 is that under Profile #3 and configuration 1 when armed with BL755 bombs and dashing 100 nm, the operational requirements are not met using JP-4 but are met using JP-8.

59. The results of Table 8 also indicate a significant savings in fuel when using JP-8 over JP-4. In order to complete the same mission using JP-8 instead of JP-4, it is possible to use anywhere from approximately 600 to 900 lbs less fuel. Also, the CF-18A has had no apparent problems using JP-8 after several years of use in Europe and has operated successfully on JP-8 during Desert Shield/Storm.

CP-140 Aurora

60. Figure 7 illustrates the two mission profiles considered for the CP-140 Aurora. For each profile there are two aircraft configurations (labelled A and B). The AOI for the CP-140 was used to determine fuel flow, cruise range and True Air Speed (TAS) under any gross weight of the aircraft for each profile and configuration [12].

61. In each simulation, the aircraft cruised to an operating area and, under power of three engines, loitered on station for a definite period before returning home and landing with remaining fuel in the range: 5000 lbs ≤ fuel ≤ 5050 lbs. Tables 9a and 9b show the percent increase in TOS and cruise range respectively, generated by JP-8 over JP-4. Table 10a and 10b show the weight of JP-8 fuel over the minimum IFR reserves (5000 lbs) that the aircraft would have at landing if it completed the same mission that would have maximized the TOS and cruise range respectively of an aircraft loaded with JP-4. Figures 8 and 9 (also from Tables 9a and 9b) illustrate the operational advantage when using JP-8 in the CP-140 aircraft.

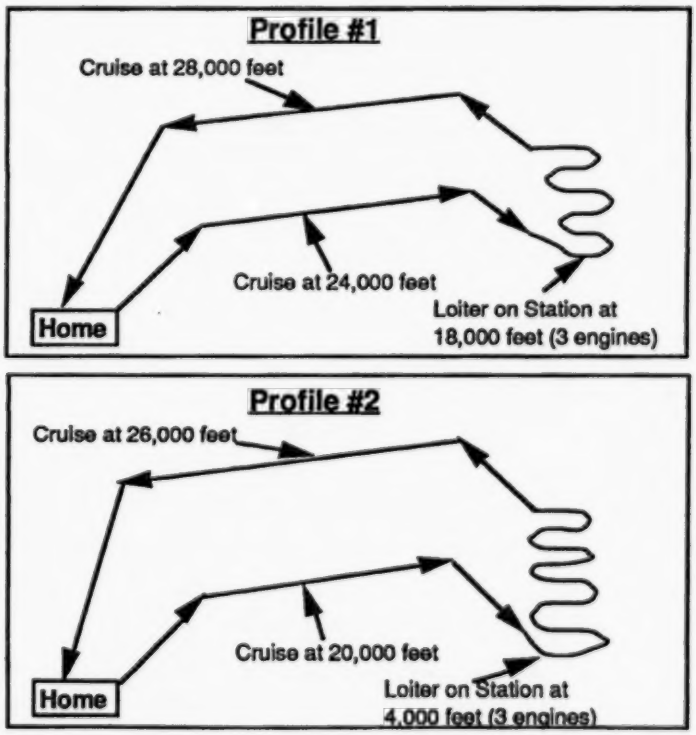


Figure 7. CP-140 Mission Profiles

Cruise Range (nm)	Config./ Profile	Time-On-Station (Hours)		
		JP-4	JP-8	%
800	A/1	8.217	8.817	7
	A/2	7.550	8.200	9
	B/1	7.650	8.217	7
	B/2	7.167	7.800	9
1000	A/1	7.117	7.767	9
	A/2	6.400	7.083	11
	B/1	6.533	7.150	9
	B/2	5.967	6.650	11
1200	A/1	5.950	6.633	11
	A/2	5.183	5.900	14
	B/1	5.333	6.000	13
	B/2	4.717	5.417	15
1400	A/1	4.683	5.433	16
	A/2	3.900	4.650	19
	B/1	4.033	4.750	18
	B/2	3.383	4.117	22

Table 9a. CP-140 Increase in Time-On-Station

Time-On-Station (Hrs)	Config./ Profile	Cruise Range (nm)		
		JP-4	JP-8	%
2	A/1	1783	1898	6
	A/2	1675	1788	7
	B/1	1683	1790	6
	B/2	1597	1704	7
4	A/1	1504	1619	8
	A/2	1385	1500	8
	B/1	1405	1513	8
	B/2	1310	1419	8
6	A/1	1193	1309	10
	A/2	1068	1185	11
	B/1	1092	1201	10
	B/2	996	1108	11
8	A/1	841	957	14
	A/2	720	838	16
	B/1	734	843	15
	B/2	652	766	17

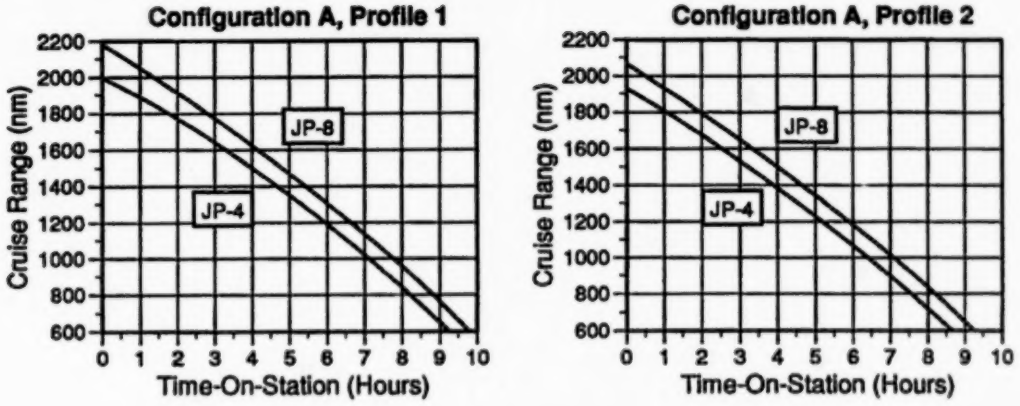
Table 9b. CP-140 Increase in Cruise Range

Cruise Range (nm)	Config. / Profile	Max JP-4 TOS (hrs.)	JP-8 Fuel Remaining (lbs)	Less JP-8 Fuel Required (lbs)
800	A/1	8.2	7230	2230
	A/2	7.6	7547	2547
	B/1	7.7	7209	2209
	B/2	7.2	7542	2542
1000	A/1	7.1	7332	2332
	A/2	6.4	7580	2580
	B/1	6.5	7297	2297
	B/2	6.0	7602	2602
1200	A/1	6.0	7374	2374
	A/2	5.2	7605	2605
	B/1	5.3	7347	2347
	B/2	4.7	7591	2591
1400	A/1	4.7	7451	2451
	A/2	3.9	7609	2609
	B/1	4.0	7392	2392
	B/2	3.4	7613	2613

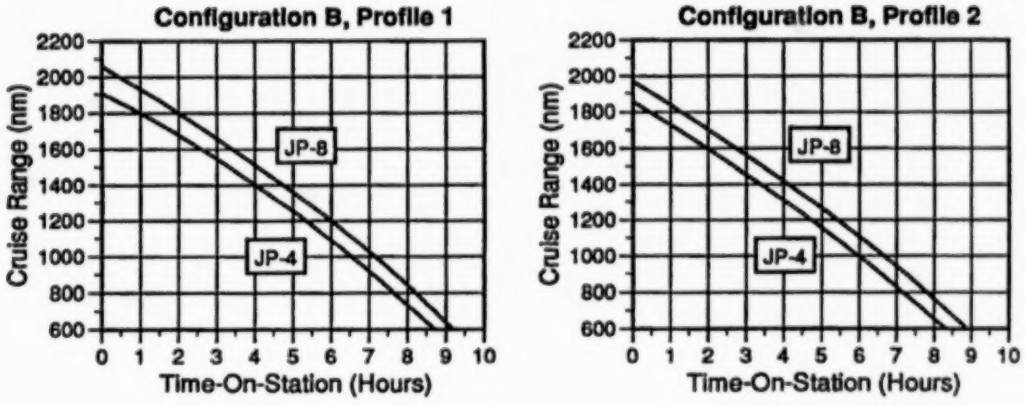
Table 10a. Reduced JP-8 Fuel Requirements For CP-140 Missions (Constant Cruise Range)

Time-On-Station (hrs.)	Config. / Profile	Max JP-4 Cruise Range (nm)	JP-8 Fuel Remaining (lbs)	Less JP-8 Fuel Required (lbs)
2	A/1	1783	7538	2538
	A/2	1675	7648	2648
	B/1	1683	7466	2466
	B/2	1597	7603	2603
4	A/1	1504	7449	2449
	A/2	1385	7605	2605
	B/1	1405	7391	2391
	B/2	1310	7579	2579
6	A/1	1193	7347	2347
	A/2	1068	7567	2567
	B/1	1092	7296	2296
	B/2	996	7568	2568
8	A/1	841	7243	2243
	A/2	720	7501	2501
	B/1	734	7177	2177
	B/2	652	7551	2551

Table 10b. Reduced JP-8 Fuel Requirements For CP-140 Missions (Constant Time-On-Station)



Figures 8 (a,b). Improvements in Cruise Range and Time-On-Station by using JP-8 (Configuration A)



Figures 9 (a,b). Improvements in Cruise Range and Time-On-Station by using JP-8 (Configuration B)

62. Since the aircraft returns with its minimum IFR fuel reserves, the results in Figures 8 and 9 represent the maximum allowable TOS for any particular cruise range and the maximum cruise range for any particular time-on-station. For example, for Profile 1 (Configuration A), if the aircraft cruises for 1000 nm, it can loiter for 7.1 hours using JP-4 or 7.8 hours using JP-8. An increase of approximately 10%. For Profile 2, the increase for the same cruise range is approximately 11%. Alternatively, if the time-on-station is fixed at 6 hours, the cruise range can increase by approximately 10% for Profile 1 and 11% for Profile 2.

63. From Table 9a, the percent increase in TOS varies from a low of 7% for the shorter cruise range (longer TOS) to a high of 22% for the longer cruise range (shorter TOS). The average increase in the TOS is 41 ± 3 minutes. Table 9b shows that the percent increase in cruise range varies from 6% for a shorter TOS (longer cruise range) to a high of 17% for a longer TOS (shorter cruise range). The average increase in cruise range is 113 ± 4 nm.

64. The results of Tables 10a and 10b indicate a significant fuel savings when using JP-8 to complete the same mission that would have maximized JP-4 usage. In order to complete the same mission using JP-8 instead of JP-4 it is possible to use anywhere from 2200 to 2600 lbs less fuel.

KC-130 Hercules

65. Figure 10 illustrates the mission profile for the typical KC-130 mission. All calculations on the KC-130 tanker were based on the variant configuration consisting of external fuel tanks and refuelling pods installed. The AOI for the CC-130 was used to determine distance, fuel flow, TAS etc. all points in the profile [13].

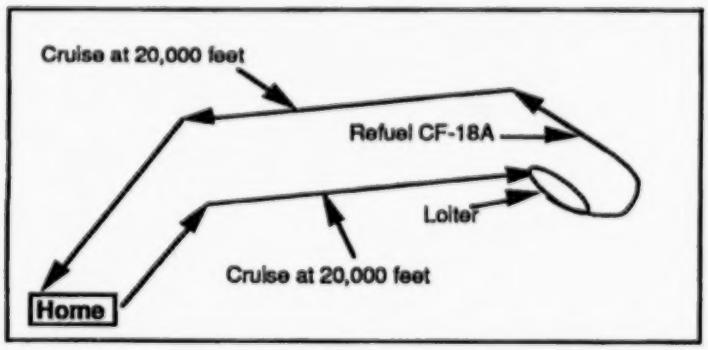


Figure 10. KC-130 Hercules Mission Profile

66. In terms of fuel capacity, there are stress factors to be considered when distributing fuel in the KC-130. For instance the wing tanks are weight (not volume) limited and structural damage may occur if their capacity is exceeded. However, the tanker configuration has an additional 3600 gallon tank in the cargo compartment which is volume (not weight) limited and could be used to carry JP-8.

67. In its role as a tanker, the KC-130 would cruise to a rendezvous point loiter for a period of time, meet the CF-18's and refuel each fighter before returning home to land with remaining fuel in the range:

6500 lbs ≤ fuel ≤ 6560 lbs. The cruise range, loiter time and fuel expended were calculated for eight different refuelling operations consisting of refuelling up to 6 CF-18's with 10,000 lbs of fuel each (Figures 11a – 11f) and refuelling 1 and 3 CF-18's with 15,000 lbs each (Figures 12a and 12b)[2]. Tables 11 and 12 show the weight of JP-8 fuel over the minimum IFR reserves (6500 lbs) that the aircraft would have at landing if it completed the same mission that would have maximized the loiter time and cruise range of an aircraft loaded with JP-4.

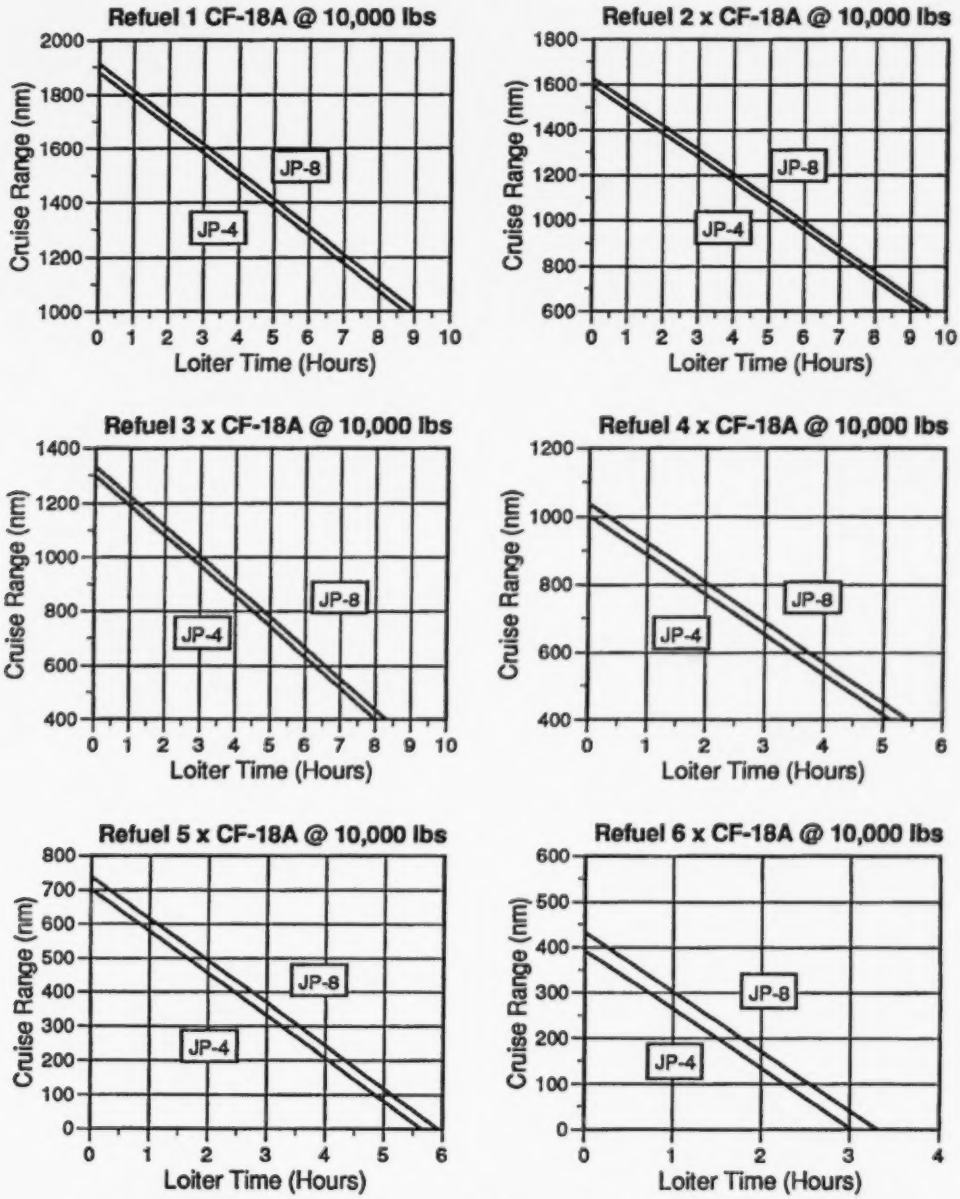
68. Figures 11 and 12 show the operational impact of utilizing JP-8 in a typical KC-130 tanker mission. Use of the fuel increases KC-130 range by 30–50 nm or loiter time by 16–20 minutes. Although these benefits are marginal, a substantial operational improvement can be achieved in the energy off-loaded to the CF-18 aircraft as shown in Tables 7 and 8[3].

69. The results shown in Tables 11 and 12 indicate a significant operational improvement when using JP-8. In order to complete the same mission using JP-8 instead of JP-4 it is possible to use anywhere from approximately 900 to 1200 lbs less fuel.

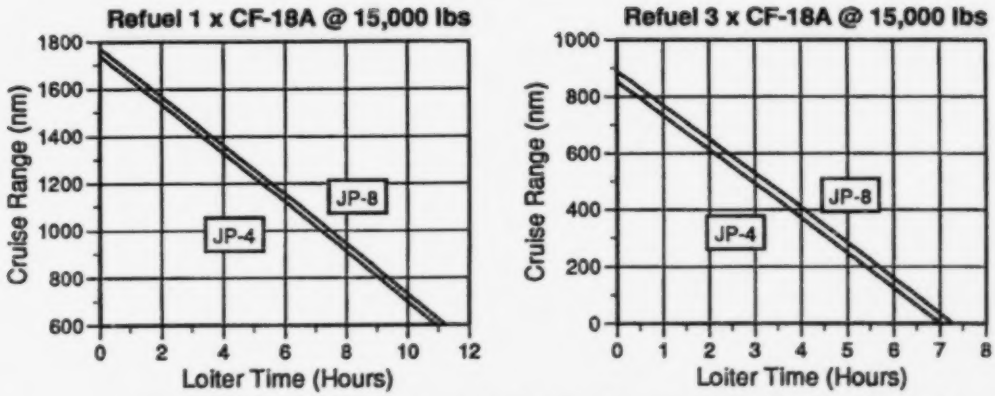
70. An important point that should be noted is that the fuel tanks located on the wings of the C-130 aircraft are weight limited and not volume limited. Therefore, if this analysis were determining the increase in cruise range and loiter time due to JP-8 usage, there may not have been significant savings realized since the aircraft would not be able to carry the full amount of JP-8 due to JP-8's higher density. It should also be noted that the CC-130 transport aircraft will obtain similar savings as the KC-130 tanker with the use of JP-8.

[2] Results for 2 or 4 aircraft refueled with 15,000 lbs each are not included since they are approximately equivalent to refuelling 3 and 6 aircraft respectively with 10,000 lbs each.

[3] The results are marginal because the wing fuel tanks are weight (not volume) limited. While JP-4 would fill the wing tanks to maximum volume, JP-8 would not, hence, there would be no energy gain. On the other hand, the tank in the cargo compartment is volume (not weight) limited and the approximately 6% gain in energy is based solely on maximizing its 3600 gallon capacity with JP-8.



Figures 11 (a–f). Improvements in Cruise Range and Loiter Time in Aerial Refueling by KC-130 Aircraft



Figures 12 (a,b). Improvements in Cruise Range and Loiter Time in Aerial Refueling by KC-130 Aircraft

Refuelling Operation	Cruise Range (nm)	Loiter Time (hrs.)	JP-8 Fuel Remaining (lbs)	Less Fuel Required (lbs)
1 CF-18 @ 10,000 lbs of fuel	1200	6.8	7478	978
	1400	4.8	7492	992
	1600	2.8	7354	854
	1800	0.8	7516	1016
2 CF-18's @ 10,000 lbs of fuel each	800	7.5	7482	982
	1000	5.6	7491	991
	1200	3.7	7565	1065
	1400	1.9	7574	1074
3 CF-18's @ 10,000 lbs of fuel each	500	7.2	7536	1036
	700	5.4	7536	1036
	900	3.6	7597	1097
	1100	1.8	7587	1087
4 CF-18's @ 10,000 lbs of fuel each	200	6.8	7556	1056
	400	5.1	7599	1099
	600	3.5	7641	1141
	800	1.8	7666	1166
5 CF-18's @ 10,000 lbs of fuel each	200	4.1	7673	1173
	400	2.5	7692	1192
	600	0.8	7684	1184
6 CF-18's @ 10,000 lbs of fuel each	50	2.7	7722	1222
	150	1.9	7738	1238
	250	1.1	7729	1229
	350	0.3	7763	1263

Table 11. Reduced JP-8 Fuel Requirements For KC-130 Missions (1 – 6 CF-18A's Refueled @ 10,000 lbs of Fuel Each)

Refuelling Operation	Cruise Range (nm)	Loiter Time (hrs.)	JP-8 Fuel Remaining (lbs)	Less Fuel Required (lbs)
1 CF-18 @ 15,000 lbs of fuel	1000	7.2	7470	970
	1200	5.3	7492	992
	1400	3.3	7523	1023
	1600	1.4	7542	1042
3 CF-18's @ 15,000 lbs of fuel each	200	5.4	7610	1110
	400	3.8	7650	1150
	600	2.1	7676	1176
	800	0.5	7672	1172

Table 12. Reduced JP-8 Fuel Requirements For KC-130 Missions (1, 3 CF-18A's Refueled @ 15,000 lbs of Fuel Each)

Additional Operational Considerations

71. A lower altitude relight envelope has been experienced with JP-8. Also, low temperature ground starts are limited to temperatures above -42°C, depending on the system. Various studies concerning altitude relight and low temperature starts have concluded that operational or flight safety limitations apply to JP-8 use for some CF land-based aircraft not included in the analysis of this report [1, 15, 16][4]. They are:

a. CH118/135/136 Fleets: Use of JP-8 reduces the cold weather start-up capability of these helicopters. Helicopter start-ups are limited to -18°C instead of -30°C for the CH118 and to -30°C instead of -40°C for the CH135/136. Note: phase out of these helicopter fleets and replacements by the CH146 is scheduled for completion by January 1998.

b. CH146 Fleet: Use of JP-8 reduces cold weather start-up to -30°C instead of -40°C with JP-4.

72. Table 13 lists the Groups, Wings and Squadrons that could convert to JP-8 and the operational impact of the conversion [15]. To date, all helicopter squadrons except 408, 427, 450 and 1 and 2 Tactical Air Wings should have converted to CH146 aircraft. The remaining conversions should be completed by Jan 1998. With a conversion to JP-8, start-up limitations for all helicopter squadrons would be -30°C vice -40°C for JP-4.

[4]On arctic operations such as OP BOXTOP, CC130 aircraft are refueled at the USAF base in Thule, Greenland with JP-8. Cold starts have not been a limiting factor for Hercules operations in the arctic

73. Additionally, JP-8 is known to increase coking or carboning of the fuel nozzles and combustion chambers thereby increasing the requirements for more aircraft maintenance [18].

Group	Wing	Squadron	Conversion Date	Ops Impact
Air Transport Group	8	412, 424, 426, 429, 436, 437	Can be Immediate	nil
"	9	103 RU	"	"
Fighter Group	3	425, 433	"	nil
"	3	439	"	cold wx start-up
"	4	410, 416, 441	"	nil
"	4	417	"	cold wx start-up
"	5	444	"	"
Maritime Air Group	12	406, 423, 443	"	nil
"	14	404, 405, 413, 415, 434	"	"
"	19	407, 414, 442	"	"
10 Tactical Air Group	11	403, 408, 427, 430	Jan 98	cold wx start-up
"	1	401, 438, 450	"	"
"	2	400, 411	Currently uses JP-8	nil
Air Command	15	2 CFFTS, 431	Can be Immediate	"
"	17	3 CFFTS, 402, 435	"	"

Table 13. Operations Impact of Conversion to JP-8 for AIRCOM Wings

6 - SAFETY, HEALTH AND ENVIRONMENTAL CONSIDERATIONS

74. Low volatile fuels (JP-8) are in general safer than high volatile fuels (JP-4) at fuel temperatures most generally experienced in aircraft and ground operations. JP-8 essentially has no vapour pressure at ambient conditions thereby making it safer to handle than JP-4.

75. As a result of JP-8's lower volatility, the following is concluded in terms of aircraft operations:

a. JP-8 reduces the possibility of in-flight and post-crash fires;

b. JP-8 is less susceptible to fire and explosion induced by gunfire; and

c. JP-8 provides an overall superior aircraft combat survivability posture compared to JP-4 [2].

76. With regards to ground operations, in situations where fuel leakage or spills may occur, the low volatility of JP-8 should preclude the formation of flammable vapours. If a fire should occur, the time to extinguish the blaze or the evacuation of the area could be of significant advantage with JP-8 in lieu of JP-4. Also, the elimination of JP-4 vapours would enhance safety during hot refuelling where one engine continues to run on a multi-engined aircraft.

77. Aside from the safety considerations, there are also health considerations involved in the conversion from JP-4 to JP-8. With the conversion to JP-8, there will be less respiratory threat from benzene, neurotoxicity will be decreased and bone marrow toxicity will be decreased. There will, however, be a higher threat from skin absorption.

78. Conversion to JP-8 would virtually eliminate the raw hydrocarbon vapour emissions from storage tanks and handling associated with JP-4. The oxides of nitrogen are expected to be the same for JP-4 and JP-8 since nitrogen oxide concentration depends on cycle temperature and not on fuel properties. Some of the downfalls resulting in a conversion from JP-4 to JP-8 include increased smoke emissions from aircraft engines and an increase in unburned hydrocarbon and carbon monoxide emissions.

79. Although no environmental legislation exists on the maximum sulfur content of aviation fuel when burned, the sulfur content of JP-8 (0.1% – 0.3% per volume) is smaller than that of JP-4 (0.1% – 0.4% per volume). According to Esso Imperial Oil, legislation enforcing low sulfur fuels could come into place [17]. Therefore, the conversion from JP-4 to JP-8 would also be more environmentally friendly.

7 - SUPPLY AND AVAILABILITY

80. The cost advantage previously associated with JP-4 has been disappearing gradually due to reducing JP-4 refinery production in Canada. It is expected, possibly in the near future, that the cost advantage will then belong to JP-8 because there will be less competition for supplying JP-4.

81. Despite the fact that only 8% of a barrel of crude is suitable for refining into JP-8 fuel, there is sufficient stocks of JP-8 on the world market to meet any increase in demand brought about as a result of conversion [2].

82. Interoperability with NATO nations and world-wide availability of JP-8 is a significant factor in considering standardization to JP-8. There is virtually *no* JP-4 fuel available in Europe. This conversion

would bring Canada one step closer to the US concept of "one fuel for the battlefield" and its logistic multiplier effect.

8 - CONCLUSIONS

83. This study compared the quantitative and qualitative factors associated with the conversion to JP-8 for CF land-based aircraft. The potential economic impact of conversion was studied and some of the qualitative factors involved in conversion were discussed.

Increased Cost From Purchasing JP-8

84. The effects on purchasing JP-8 fuel over JP-4 fuel (overall fuel costs over a one year period) at each of the four Wings are as follows:

a. 4 Wing Cold Lake: For 94.5 million litres of JP-8, the cost increase varied from $1.6M (@ $0.260/L) to $7.4M (@ $0.320/L). Assuming an average JP-8 price of $0.293/L, the cost increase of purchasing JP-8 is approximately **$4.8M.**

b. 8 Wing Trenton: For 36.8 million litres of JP-8, the cost increase varied from -$1.1M (a net savings @ $0.260/L) to $1.1M (@ $0.320/L). Assuming an average JP-8 price of $0.293/L, the cost increase of purchasing JP-8 is approximately **$0.12M.**

c. 14 Wing Greenwood: For 33.1 million litres of JP-8, the cost increase varied from -$0.58M (a net savings @ $0.260/L) to $1.41M (@ $0.320/L). Assuming an average JP-8 price of $0.293/L, the cost increase of purchasing JP-8 is approximately **$0.53M.**

d. 19 Wing Comox: For 22.7 million litres of JP-8, the cost increase varied from $0.040M (@ $0.280/L JP-4) to $1.0M (@ $0.240/L JP-4). Assuming an average JP-4 price of $0.260/L, the cost increase of purchasing JP-8 is approximately **$0.5M.**

85. From the above, the total increased cost from purchasing JP-8 varies from a savings of $40,000 (if the lowest fuel cost in a–d is used) to a cost increase of $10.91M (if the highest fuel cost in a–d is used). Based on the average cost of JP-8 ($0.293/L) the cost increase for purchasing JP-8 is approximately $5.95M for all four Wings. However, since the main driver in this cost benefit analysis is 4 Wing Cold

Lake, and since the current cost of JP-4 at Cold Lake is $0.03/L less that the average, we can hypothesize that the cost of JP-8 may also be significantly less than the average. Therefore, using a JP-8 price of $0.26/L for 4 Wing, the cost increase for purchasing JP-8 is approximately **$2.75M** for all four Wings ($1.6M + $0.12M + $0.53M + 0.5M).

Anticipated Savings

86. Anticipated savings from JP-4 to JP-8 conversion are as follows:

a.	Fuel vapour purging of bulk storage tanks:	$8000. (accrued every 3–5 years)
b.	Losses due to evaporation (Working Losses):	$40,000. (accrued annually)
c.	Losses due to evaporation (Standing Losses):	$120,000. (accrued annually)

Therefore, the total anticipated annual recurring savings from JP-4 to JP-8 conversion is approximately **$0.162M.**

87. Also, as a result of conversion, a *possible* one time savings of approximately $750,000 (U.S.) ($975,000 CAN) would be achieved if, due to stricter environmental regulations, Canadian emissions standards forced the CF to lower its fuel vapour emissions into the atmosphere. This cost to the department does not presently exist but may be incurred if JP-4 remained the primary aviation turbine fuel. It was also determined that there will be no savings realized in fuel servicing operations or aircraft maintenance costs due to a conversion.

Operational Impact

88. The results of this study show substantial gains in operational performance using JP-8 instead of JP-4. These gains are, however, difficult to quantify and are not included in any net savings.

89. For the CF-18A, a higher density fuel not only extends the operating range but in certain cases allows the mission requirements to be fulfilled which would not have been possible if JP-4 had been used. The CP-140 can add approximately 41 ± 3 minutes to fulfilling its ASW role or extending its operating range approximately 113 ± 4 nm beyond its normal limits. For the KC-130, the impact is marginal. Use of JP-8 increases the range by 30–50 nm or loiter time by 16–20 minutes. However, the refueled fighter aircraft are then able to patrol over longer distances and for longer times, thereby decreasing the number of missions and the number of aircraft needed to patrol while increasing the patrol area.

90. It is concluded that a conversion from JP-4 to JP-8 would result in a quantified net loss to the CF of approximately $2.6M. However, this loss is largely attributed to the sensitivity in the purchase price and the cost increase incurred at 4 Wing Cold Lake. Since 4 Wing purchases such large quantities of jet fuel, a difference of $0.01/L in the purchase price translates into a $1.0M cost increase. If a much lower price than the average JP-8 price of $0.293/L can be acquired, then the cost increase, and the net loss to the CF, would be much less.

9 - RECOMMENDATIONS

91. Based on the results of this study, the following is recommended.

a. Complete engineering studies be undertaken on the refuelling trucks to determine their reaction to JP-8.

b. More accurate costs for production and implementation into service should be determined.

c. Although little or no conversion is required for most aircraft types to use JP-8, a maintenance review should be conducted for related fuel systems, especially addressing coking problems noticed in the CH113 (Labrador) aircraft using JP-8.

d. It is recommended that conversion to JP-8 take place provided that operational limitations with regards to cold weather start-up for the CH146 (Griffon) be addressed.

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1. This study compares the quantitative and qualitative factors associated with the conversion to JP-8 aviation turbine fuel for Canadian Forces (CF) land-based aircraft. The potential economic impact of conversion is studied for 4 Wing Cold Lake, 8 Wing Trenton, 14 Wing Greenwood and 19 Wing Comox. The operational impact of conversion is studied for the CF-18A (Hornet), the CP-140 (Aurora) and the KC-130 (Hercules) aircraft.

2. It is concluded that a conversion from JP-4 to JP-8 would result in an annual net loss to the CF of approximately $2.6M. It was further determined that the net loss is highly sensitive to the JP-8 purchase price due to the large volumes of fuel that must be purchased. However, taking into account the net loss and the positive affects in regards to safety, health, environmental considerations and operational benefits, it is recommended that conversion to JP-8 take place provided that operational limitations with regards to cold weather start-up for the CH146 (Griffon) be addressed.

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